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INDUSTRIAL UTILIZATION OF CORN CROP RESIDUES

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Food and energy in abundance are basic to a peaceful world. In food-producing ability, American agriculture surpasses the rest of the world not merely because of fertile soils but because of the enormous research effort we have directed to food and feed production.

The contribution that agriculture may make to supplying useful forms of energy other than food has received relatively little research attention. But everyone knows that, aside from atomic energy, all of our energy sources and reserves, such as coal, petroleum, gas, shale, and lignite have their origin in plant life.

Food is derived as an annual income of energy from the sun. Although our fuel reserves were built up by the same chemical and sun-energy processes during millions of years, yet in our agricultural residues and the waste in our forests or lumber mills there is an enormous annual income of useful energy, available if we can but intelligently employ it.

Plants use sun-energy to synthesize carbohydrates, proteins, and fats from carbon dioxide, ammonia, and water. By adding energy from the sun to simple compounds of low-energy level, compounds of high energy are synthesized. Human and animal life subtracts this sun-energy by chemical reactions which again gradually reduce the high-energy compounds stepwise to those of lower and lower energy levels.

Our annual harvest of food and feed represents considerably less than half our crop production, the remainder being in the form of dry stalks, straws, hulls, cobs, and the like. Since these residues are almost devoid of proteins or fats, they are of no direct value as food and of little value as feed. However, they consist of cellulose, the hemicelluloses, and lignin, which are all high-energy compounds. Almost none of this energy is used in a controlled way or at all efficiently. The largest portion is slowly lost in the form of heat as the residues are

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converted by natural processes of decay to carbon dioxide and water. And I need not remind you that millions of tons are burned in the fields to the same end-products, with absolutely no energy utilization whatsoever. Of the estimated 250 million tons of residues annually produced, only about 2 million is used for some industrial purpose, mainly for the manufacture of paper or board. Perhaps 3/4 million tons is used for fuel. On the farm, perhaps 30 million tons is used for bedding, fed as roughage, and used as mulch, while the remainder is plowed into the soil or burned.

Taking into account that crop residues play an important part in maintaining soil fertility, yet perhaps 100 million tons of them might find annual industrial utilization. The war has brought a realization of the rapid depletion of our resource reserves, and this, together with a vigorous increase in population, may make necessity, rather than choice, the deciding factor in putting this vast annual supply of energy from the sun to efficient use.

This problem of farm residue utilization as yet holds little attraction for industry, but it is of supreme importance to agriculture and to our future economy. A sound agricultural and industrial economy requires the most efficient use of residues, which in turn will produce a maximum return to agriculture.

The federally-financed effort to solve the problem of agricultural residue utilization was assigned to the Northern Regional Laboratory in Peoria, Illinois. This problem is not new. Thousands of scientific papers, patents, and descriptions of processes for the industrial utilization of one or another of these residues are found in the literature. On the other hand, successful industrial utilization of any permanent character, in the light of the effort already expended, has been very small.

With such a background of failure, the development of a rational, long-range program for a successful solution of this problem of waste utilization, when we started in 1939, was more than ordinarily difficult. But by studying the successes and failures in this and other waste utilization fields, several rather simple guiding principles for research were developed. Such success as the few succeeding years have brought to this work is due to adherence to these principles.

These principles may be stated briefly:

1. Establish procurement of the residue on a sound economic basis. This involves collection, packaging, transportation, storage, and preservation and sound contractural relationships with suppliers.

2. From a thorough study of the physical and chemical properties of the residue, determine wherein it may render services in industrial usage not so readily

supplied by other raw materials. Establish uses based on its superior or unique properties.

3. In development of processes to utilize a residue, eliminate waste products to the greatest possible extent. Attempt to obtain maximum utilization by producing major co-products instead of byproducts or wastes.

4. Recognize that markets must be explored, merchandising plans perfected, and proper financing arranged before making investment in plant facilities. Sound business management and sound merchandising of the product will prove as important to success as a sound conversion process, operated on an economical competitive basis.

This symposium is directed to a discussion of the corn crop. The residues which may be secured from this crop are:(a) tassels, (b) leaves, (c) stalks, (d) cobs, and (e) husks.. Annually these total approximately 80 million tons of dry matter. Of this, only about 200,000 tons of cobs and a few tons of husks are now finding industrial use. The remainder stays on farms. Some is used for bedding, some for kitchen fuel, some for fodder, more is grazed in the field, much is used as mulch or plowed back, but a considerable proportion is just sheer waste.

FARM USES

Residues should find their first use on the farm. But it should be profitable farm use, and above all intelligent. When the only recourse left is use on the farm, little incentive remains to avoid wasteful practices and apply more intelligent methods. When residues can be used for bedding they should not be removed from the farm. When they can be used as feed their value is much greater than as raw material for industry. Those parts of the residues containing protein, such as leaves and tops, are better for plowing back to maintain fertility than are the parts containing practically none, such as stalks proper.

Shredded corn stalks make excellent bedding. Their high pith and leaf content make them very absorptive, they rot well in composting, and the manure spreads easily. In those communities where there is an industrial or off-farm demand for wheat or oat straw, the substitution of shredded corn stalks as bedding should prove both beneficial and profitable.

Tassels and leaves both have recognized feed value. Husks are sold for feed. The practice of feeding ground corn-and-cob meal to cattle has long been practiced in many localities. According to Morrison (1) the leaf of the corn plant compares favorably with timothy hay in nutritive value. In the practice of allowing the stalks to stand in the field for forage, much of this leaf matter blows away and is wasted. Saving of the leaves and tops of the corn plant for feed is fairly common practice in the southern areas of the United States. Brodell and Walker (2) report that in 1943 for the whole country the leaves were stripped or the tops were cut on 3.6 million acres. Van Lanen, Tanner and Pfeifer (3) of the Peoria Laboratory report that about 50,000 tons of dry corn tassels resulted from hybrid seed corn production in 1944. They conclude from a study of the composition of the tassels at various stages of pollen maturity that tassels are a good source of protein and vitamins and attain their highest nutritive value at normal detasseling time. Dried tassels may be a suitable adjunct to poultry feed. To date, no industrial production of this type of feed has been undertaken, the economics of collection and drying being questionable.

Recent work published on the feeding of ground corn-and-cob meal in livestock rations shows the benefits from this practice. The Wisconsin Agricultural Experiment Station (4) reports that grinding ear corn for steers is a very worthwhile practice if hogs do not follow the steers. Burroughs and Associates (5,6) of the Ohio Agricultural Experiment Station, from feeding experiments with steers, state that their data suggest that cobs for cattle are 64 percent as valuable as the grain itself for energy or for fattening purposes. Concurrent with the feed shortage in 1946, many carloads of cobs, ground through a hammer mill to pass a 1/8-inch mesh screen, were shipped to feed dealers. Many states have laws prohibiting the use of ground cobs in mixed feeds. This use of ground cobs warrants much more study by State Experiment Stations and feed manufacturers. Fine fractions, such as beeswing, pith, and other particles, obtained in the grinding of cobs for industrial purposes, which now find a very limited market, could find profitable use in feed if regulations permitted.

There is generally a large demand for a good molasses absorbant in the manufacture of high-carbohydrate feeds. Our tests show that cobs ground to pass a 1/8-inch mesh screen will easily absorb their own weight of blackstrap molasses to form a product which is free-flowing and not sticky.

AVAILABILITY, COLLECTION AND STORAGE

It is estimated that 20 million tons of corncobs are produced annually. About 3.5 million tons of cobs result from corn sold off the farm, of which Iowa and Illinois account for about three-fifths while Indiana, Ohio, Minnesota, Missouri, and Nebraska also produce large quantities.

Before the war only one company processed cobs for the industrial market, using about 10,000 tons annually. At present, about 200,000 tons are used. The demands of the war brought about this increase, and between 40 and 50 rural cob grinding plants were set up to fill this need. Quite a few of these plants are still in production and the industrial utilization of cobs is increasing.

Cobs had been favorably considered as a raw material for industrial use by several large companies prior to 1940, but it was concluded that it was impossible to collect them at low enough cost in large tonnage. A survey by the Northern Regional Laboratory in 1941 (7) laid a sound basis for the industrial use that has followed.

Cobs that accumulate at country mills, elevators or at hybrid-seed plants would appear to be the easiest and cheapest source, particularly if operators grind the cobs. Experience shows that it is also practical and economical to secure cobs from farm shelling operations. In many cases, cobs have a negative value on the farm. They must be removed from the barn-lot where the shelling takes place because they are both a fire hazard and a nuisance. Commercial shellers have been glad to arrange for cob suppliers to provide trucks at farm shelling operations, so that the cobs may be loaded directly into them and hauled away. While neither the farmer nor sheller receives money for the cobs, this service proved valuable to them.

Our surveys show that in Illinois, for example, there are several areas where 200,000 to 250,000 tons of cobs could be secured within a radius of 50 miles from farm shelling operations; also, that 100,000 tons of cobs collect annually at elevators within a radius of 80 miles of one locality in Illinois and 42,000 tons in an area 150 miles long and 40 miles wide in Indiana.

An expanding industrial utilization of cobs depends on the processor's ability to obtain them in large quantities without paying too much for transporting them. A number of problems, such as better types of trucks for hauling cobs, better management in working with shellers, improved low-cost machinery for loading and unloading cobs, and better methods for grinding cobs are now receiving attention by industry. The Agricultural Engineering Department of one of the Corn Belt States has become interested in the solution of these and collateral problems. It is hoped that other agricultural engineers may follow this lead.

The storage of corncobs for industrial use has recently been given consideration by Winter, Dunning and Dallace (8). At the time of harvest, cobs contain about 20 percent moisture. They take up water easily from rain and snow, and wet cobs are costly from the standpoint both of transportation and grinding. Cob products for many uses should not contain more than 13 percent moisture. Small cob processors generally store whole

or ground cobs under cover in cheap structures with slatted sides to permit circulation of air. However, these authors conclude that a chemical process requiring 100,000 tons of cobs per year, such as for the production of sugars or liquid fuels, storage of whole cobs for 6 months would be a maximum period. Under such conditions, whole cobs may be stored in large open piles without undergoing appreciable loss in value. Such storage should be on the site of the cob processing plant; any storage piles out in the country should be under cover to prevent high transportation costs.

Corn stalks now find no industrial use for the very simple reason that no economical method exists for collecting and storing them. Period. It is high time that the general public, and particularly farmers of the Cornbelt, know this and that they cease to be befuddled by the continual glowing press accounts of all the wonderful industrial uses of the corn stalk just over the horizon. The wishful thinking of those who say that when a technological conversion process is at hand, industry will develop methods and means for collecting and storing stalks, has been proved by experience to be futile.

Harvey Sconce of Illinois and J. B. Davidson of Iowa some years ago both made a serious attempt to work out economical methods and machines for collecting stalks, but these proved inadequate. The mechanization of farm machinery is progressing rapidly and a solution of this problem is not impossible. The potential market for cornstalks is to the paper, board, and insulating building materials industries. Leaves are of no value for these purposes. Cobs are to be avoided and dirt is a serious handicap. It is felt by a number interested in this problem that if machines can be perfected to shred the stalk and bale it for bedding, a start will be made. Let us recognize, however, that the future of the industrial use of stalks at present is in the hands of the agricultural engineer and the farm equipment manufacturer.

The fiber-using industries require uniform, all-year raw material supply. This means that baled stalks would have to be stored for at least a year. There must be only negligible loss in the quantity and quality of the fiber. This poses a most difficult problem. The insulating board plant in Iowa which used cornstalks for about 15 years gathered them in mid-winter when the leaves were largely gone and when the stalks were dry. Such baled material kept well stored in large stacks. But the use of stalks by this company has been abandoned because of cost. If the stalks are harvested in the fall they will contain 40 to 60 percent moisture, depending on the weather. There is not enough fermentable sugar present in the mature stalk to start a strongly exothermic fermentation process to drive out the moisture, as takes place in the storage of bagasse. Furthermore, the winter climate limiting useful fermentation and subjecting outside storage piles to rains and snows, makes the problem more difficult than with wheat or seed flax straw, and bagasse.

Any experimental work looking to a solution of this storage problem will not prove successful unless piles of at least 100 tons each of stalks are used to work out proper conditions.

INDUSTRIAL USES OF CORN CROP RESIDUES

The voluminous technical literature on the utilization of these residues is of little value to the industrial realist. Most of the studies have been neither of a very fundamental nor a practical nature and the questions of costs and of industrial feasibility have generally been ignored. The present discussion will be limited to processes in actual use, or those which are capable of use under some improvement in raw material procurement.

Uses may be based either on capitalizing unique physical or chemical properties, or, as in some cases, on a combination of the two. Processes based on chemical treatment of the residues generally require high capital investment and considerable technical control and are not attractive to small business. Mechanical processing, however, has proved quite suitable for rural industry.

USES BASED ON PHYSICAL PROPERTIES

Corncobs have unique physical properties which are being put to many industrial uses. A cob is composed of four rather distinct parts: light chaff or beeswing; course chaff in the form of tough, wood-like flakes; pith; and a woody ring. The ring and course chaff are tough, woody, resilient, and resistant to abrasion and granulation. These two parts constitute 94 percent of the entire cob.

Perhaps the oldest industrial use for cobs is the manufacture from them of tobacco pipes. Three companies in Missouri engaged in this business use approximately 15 million cobs per year. A special type of stocky, white cob with small pith center, which is obtained from farmers in the Missouri River bottoms, is required for this purpose.

For other industrial uses the cob must be ground into fractions which are graded by screening and often blown free of dust. Cobs are difficult to grind. Rugged hammer mills are suitable for grinding to sizes passing a half-inch mesh screen at a production rate of about 125 pounds per horsepower-hour. Wet cobs require more power in grinding, and, if above about 25-percent moisture content will plug in the burr-type cob grinder. Hammer mills are not very suitable for finer grinding. For such purposes the disk attrition mill, roller mill, or cutter mill should be used. Precautions must be taken to avoid fire. The injection of steam in small amounts into the cyclone system is an important precaution. (7)

For about 10 years before World War II, a mill in Ohio successfully manufactured ground cob products. These were sold for purposes such as, fur cleaning, burnishing of metal parts, use in floor sweeping compounds, and for other small uses.

The war brought about large expansion in the use of cob particles for burnishing of ordnance and other metal parts. Particles passing a No. 12 and retained on a No. 35 U. S. Standard screen are suitable for this purpose. While the tonnage of cobs for this use has fallen off since the war, civilian use has increased. For example, one of the largest manufacturers of roller and ball bearings has standardized on the use of cobs not only for burnishing but for polishing. For polishing, particles passing a No. 35 and retained on a No. 60 mesh screen are used. The use for this polishing agent has been extended to brass and tinplate, aluminum ware, optical glass, metal pencils, and like articles.

A new and most interesting use for cob particles, passing a No. 12 and retained on a No. 35 mesh screen, was developed by the Peoria Laboratory in cooperation with the Bureau of Aeronautics of the Navy. This is known as the soft-grit blasting method for cleaning metals. (9)

Essentially, soft-grit blasting consists of forcing a mixture of ground cobs and whole rice hulls, by air pressure, against the metal to be cleaned. Almost every kind of deposit except hard mill scale can be removed. Since the soft grit is not abrasive, the cleaning process does not cause dimensional changes in the parts, and neither masking of parts nor use of hand tools is required.

Early in World War II, the Navy tested many materials in an effort to speed up the cleaning of its aircraft engines prior to overhaul. Food or feed products such as wheat and hominy grits were tested, and clover seed and similar materials were tried out. Because of the lead in the carbon removed from the engines, the waste from the process was unsuitable for subsequent use as feed or in fermentation processes. The Army, in its tests, tried ground nutshells and cellulose acetate pellets, but these materials were scarce or too expensive.

This preliminary work led to a request in 1943 for the aid of the U. S. Department of Agriculture, which turned the problem over to its Northern Laboratory, at Peoria. Research engineers there eventually recommended corncobs and rice hulls as soft-grit material, and the Navy, at its Norfolk, Virginia, Naval Air Station, after considering such factors as availability, initial cost, total period of usefulness, and operating efficiency, adopted as standard this nonfood, abundant, and cheap material.

Soft-grit blasting follows degreasing of the metal to be cleaned. The soft grit is used in standard blasting equipment operating under 80 to 90 pounds pressure. The operator stands outside a small booth and holds

the parts to be cleaned inside the enclosure in which the dust and grit particles are confined. The resilient grit particles are automatically separated from the dust and dirt and returned to be used over until they are worn out. The Navy found that soft-grit blasting saved man-hours, because metal parts could be cleaned 4 to 10 times as fast as by older methods. The process proved almost foolproof and could be used by unskilled operators who, by older methods, often damaged pistons and parts so that they had to be sent to the scrap heap.

Preparation of the soft grit is simple. Cobs are first crushed and then ground in an attrition mill. The useful particles are those that pass a No. 12 screen but are retained on a No. 35 screen. The pith and beeswing chaff are removed by air blast, leaving 50 to 60 percent of particles of acceptable size. The rice hulls are used whole. Although they contain about 18 percent of silica, which makes them slightly abrasive to steel, in the quantity used in the mixture they do no damage.

Since the war, the method is finding use in the cleaning of parts in the repair and rebuilding of automotive engines. For example, a company rebuilding 400 to 500 automotive engines per day has been using soft-grit blasting for more than a year. A Peoria motor company has stated that use of this method enabled them to stay in the automotive spare-parts business. The process is being used in the rubber industry for cleaning molds and matrices for new tires, recapping, and hard rubber, and in the glass industry for cleaning molds. The method has been found satisfactory for cleaning aluminum foundry molds, core boxes, and grids for battery boxes. It should find particular application in cleaning parts made from soft alloys where dimensional tolerances are important. The Navy used about 500 tons of corncob grits. It is difficult to estimate present usage, but one of the companies producing cob grits states that its business is growing.

There is a large and growing market for ground cobs as chicken litter. Particles passing a No. 2 and retained on a No. 8 screen, fanned free of dust, are acceptable. We have recently shown that white cob particles passing a No. 35 and retained on a No. 80 screen are an excellent substitute for corn meal as a mild abrasive in toiletries for cleaning the skin. Particles from red cobs will stain such preparations because of the alkaline character of the compounds. Popcorn cobs would be a suitable source for such abrasives.

It has been suggested many times that corncob flour (particles passing a 100-mesh screen) should be suitable as a filler in plastics. We have shown that under certain conditions of compounding with phenolformaldehyde resins, plastics meeting general A.S.T.M. strength specifications can be obtained. (10,11) Cob flour is rather expensive to produce and wood flour is a standard with the industry, the plants of which are located mainly in the East. Freight rates and established usage of wood flour seem to indicate little use of cob flour at present.

In setting up a successful cob-grinding business, provision should be made to find a sales outlet for all cob fractions produced, and as little regrinding of fractions as possible should take place to avoid excessive costs. If the processor could find a market as feed for the fines produced, and which are now wasted, this should make the business more stable. Prospective processors must take into account the predominant part that merchandising ability plays in the success of such ventures.

Cornstalks are sometimes roughly ground and used as loose-fill in the insulating of farm buildings. Loose fills of this type are unsuited for the industrial market, since they cannot compete with bats made from glass or rock wool, or wood fiber treated with fireproofing salts and insect repellants. An industrial market might be developed with the railroads and stockyards in the use of baled shredded cornstalks as bedding.

Husks are a nuisance in grinding cobs, since they tend to plug the grinder. Some grinders remove them by attaching a suction fan to the grinder feed. Most of the husks are sucked through the fan and collected in bags. They have been sold as feed and as a packing for ceramic ware. They are said to be preferred to wood excelsior for the latter purpose. Husks have also been used as stuffing for cheap mattresses. They could be used by the strawboard mills for board manufacture if they could be supplied in large enough tonnage. They would require baling for this use.

INDUSTRIAL USES BASED ON CHEMICAL PROPERTIES

The largest use for cobs, perhaps 150,000 tons per year, is for the manufacture of the important chemical, furfural. Two large plants, one at Cedar Rapids, Iowa, the other at Memphis, Tennessee, which have a production capacity of more than 20,000 tons per year, make furfural. Oat hulls, originally used as a raw material at Cedar Rapids, are now insufficient in supply. Although the Memphis plant uses corncobs mainly it also uses cottonseed-hull bran and rice hulls. Furfural is derived by the action of hot sulfuric acid on the pentosans contained in these residues. Since agricultural residues are higher in pentosans, as a class, than wood, they are a preferred raw material for furfural manufacture. Cornstalks have about the same pentosan content as cobs and could also be used if they could be collected and stored at low enough cost.

Furfural now finds many important uses; as a solvent in the purification of wood rosin, petroleum lubricating oils, butadiene for manufacture of synthetic rubber, and in the separation of vegetable oils into food and paint oil constituents and for the manufacture of plastics and a variety of chemicals. It has been recently announced that about 12,000 tons per year of furfural will be used to produce a chemical required in the manufacture of nylon. (12) Other large uses in the chemical industry are indicated.

In the present process of furfural manufacture (13), the agricultural residue is heated under pressure with dilute sulfuric acid in a rotary cooker. Steam and furfural distill from the cooker and technical grade furfural is obtained by further distillation. The brown residue left in the cooker is used for fuel or as a filler in fertilizer. This residue contains the lignin, the cellulose, now badly decomposed, and what is left of the pentosans.

A process for the conversion of cobs to sugars, furfural, liquid fuels, and lignin has been under investigation on a semi-works scale for about a year at Peoria.

For a century chemists have known that, by proper treatment with acids, cellulose can be converted into the sugar dextrose, or corn sugar and that pentosans can be converted into pentose sugars, mainly xylose. Xylose by treatment with acid is converted to furfural. Dextrose when fermented with yeasts yields alcohol.

There have been many industrial attempts to produce "wood sugars" as the basis of low-cost alcohol production. Wood has been selected for processing because of its higher cellulose content and consequent higher production of dextrose required for fermentation. These processes for "wood sugar" production have had to compete with blackstrap molasses, itself a waste product of low value. To date, no process has been developed which will withstand such competition without State subsidy.

The Scholler process developed in Germany prior to World War II was of tremendous importance to the Axis powers as a source of carbohydrates for feed and as a medium for the production of fodder yeast to supply protein. Both of the sugars, dextrose and xylose, are used in fodder yeast production. The Scholler process has been investigated by the U. S. Forest Products Laboratory, and a plant based on their simplified design and more efficient operation was, for some months, in production at Springfield, Oregon, using waste coniferous woods.

In all of the wood sugar processes there has been no attempt to obtain the two types of sugars in separate solutions. In recent years, in order to improve the economics of alcohol production, an attempt has been made to obtain some value from the pentose sugars. In some cases fodder yeast has been grown on the beer slops resulting from the alcoholic fermentation. Consideration has been given also to the conversion of the pentose in the slops to furfural.

Agricultural residues, because of their lower cellulose content, have never been seriously considered as a raw material for the production of wood sugars. If these residues are to be used as a source for wood sugars, it is evident that their high pentosan content must be capitalized.

Therefore, a process yielding pentose sugars and dextrose separately, leaving a lignin residue, might be one with a sound economic basis. It would be necessary to obtain these sugars in high concentration and in very high yields. This indicated a continuous process.

Starting on this premise, Dunning and the writer (14) succeeded in developing in the laboratory a process in which 95 percent of the pentosans of corncobs could be brought into solution with dilute sulfuric acid, mostly as pentose sugars with less than 1 percent of dextrose. This concentration of pentose sugars can be brought to 15 percent. The residual cellulose can be converted in 90-percent yield to dextrose in a solution of 10 percent concentration. Langlykke, Van Lanen, and Fraser (15) at this Laboratory found a method to ferment the solution of pentose sugars satisfactorily to butanol, acetone, and alcohol. Studies under way indicate that these sugars may be converted to furfural in much higher yields than have been commercially possible with solid residues. The dextrose ferments with yeast to alcohol in industrial yields. It is possible to obtain crystalline xylose in at least 40 percent yields from the pentose sugar solution. It is probable that crystalline dextrose can be obtained in good yields from the dextrose solution. Either the pentose or dextrose sugars will serve as a medium for the production of fodder yeasts.

As a result of this work, the Department of Interior transferred funds from their Synthetic Liquid Fuels Investigations, authorized by Public Law 290, 1944, to the Secretary of Agriculture to prove this saccharification process on a semi-works scale at Peoria, Illinois. This is an attempt to obtain full utilization of cellulose, hemicellulose, and lignin from residues, of which cobs is among those best suited for economic use. The project is directed to a determination of the most practical and economical means for producing the sugar solutions and for converting the pentose sugars to furfural. Complete manufacturing process and cost data will be obtained together with engineering design data for a commercial-scale plant.

This Synthetic Liquid Fuels semi-works operation, now under way, is capable of producing 2,000 pounds of dextrose in 10 percent solution. 1,600 pounds of pentose sugars (mostly xylose) in 15 percent solution containing about 200 pounds of furfural, and 1,000 pounds of lignin residue from 6,600 pounds of agricultural residue in an 8-hour day. Since the process is continuous in operation, it is necessary to study each step of the process in turn.

This research work of the S.L.F. Project, under the direct supervision of the Chief of this Bureau, is carried cooperatively with the research program of the Northern Regional Laboratory. The sugar solutions produced are being fermented to butanol, acetone, or alcohol in the alcohol pilot plant of the Northern Laboratory. The motor fuels produced are under test in the motor fuel testing laboratory; a study of methods for crystallizing xylose and dextrose from their respective solutions is being undertaken;

and uses for lignin, other than as fuel, are being determined. The operating and cost data developed in this work will be made available to the S.L.F. Project and will be incorporated in the report on this work. From the coordinated research study it is anticipated that a conclusion may be reached (1) on the maximum amount of liquid fuel obtainable from a ton of residues, and (2) the lowest costs possible in manufacture of liquid fuel through co-production of a higher profit, merchandisable product.

Work on the first step of the operation, the extraction of the pentose sugars is almost completed. The yields of these sugars and of furfural in this step are those predicted by the Laboratory work. During the coming year the step of converting the cellulose-lignin residue, obtained from the first step in the extraction, to glucose and lignin will be studied. It will be several years before the project in all of its aspects can be completed. Cornstalks could be used in this process if they could be collected and stored at low cost.

A company in Colorado is now producing crystalline xylose of high quality from corncobs and is endeavoring to develop uses for this sugar.

USE IN THE MANUFACTURE OF CELLULOSE PRODUCTS

Satisfactory insulating building board products were manufactured from cornstalks in a plant in Iowa for 10 or 15 years. The cooperative studies of the National Bureau of Standards and Iowa State College (16) gave the impetus to this successful use of cornstalks. Recently, due to the high collection costs of stalks, their use has been abandoned in favor of wood fiber and flax shives.

For some time we have been carrying on fundamental studies on the suitability of fibrous residues for building board manufacture. Cornstalks compare rather favorably with wheat straw and sugarcane bagasse for such uses. Yields of product appear to be somewhat lower than with wheat straw. By some rather simple modification of present processes it is possible to manufacture products considerably stronger than many on the present market.

When the Regional Laboratories were organized one of the goals of their work was the possibility of developing manufacturing processes suitable for use by small rural industries. A case study was undertaken of the problems to be solved in such rural industry processes, using the manufacture of insulating building board from wheat straw as an example. (17, 18) After exhaustive work a process was developed which can produce a saleable product. Because of high labor costs and particularly since success of this small rural-plant process will depend to such a great extent on ability to merchandise the product, it is felt that generally such a rural process may fail or be marginal. Under the most favorable conditions it might succeed. With

some modifications in cooking the fiber, cornstalks might be used instead of wheat straw, but because of the status of the collection problem and the lower yields from cornstalks, it is now felt that this process would have little chance of commercial success with cornstalk use.

Corncobs are not suitable for the manufacture of such board products. Attempts have been made to produce panels and tile from coarsely ground corncobs and thermosetting resins. Manufacturing costs by such methods are high and no industrial use by this process has resulted.

Cornstalks are a satisfactory material for the manufacture of 9-point corrugating box board, to be used in conjunction with wheat straw or perhaps in replacing wheat straw. During the war, when strawboard mills experienced a shortage of straw, a number of mills experimented with small quantities of cornstalks. Some of the mill operators expressed interest in obtaining cornstalks for larger mill trials, but generally stalks were unavailable in tonnage. The yield of 9-point board from stalks is somewhat lower than from wheat straw. This is largely due to the pith content, some of which is lost in cooking and a considerable portion of which is lost in washing of the pulp. The present cooking processes, with perhaps slight modifications, could be used. Straw and cornstalks should be cooked separately.

It has long been known that paper can be prepared from cornstalks. Brand (19) of the Department of Agriculture in 1911 published Circular No. 82 on cornstalk paper made from an experimental run.

The National Bureau of Standards (20,21) in cooperation with Iowa State College (22), as well as the Forest Products Laboratory (23), studied the problems of producing paper pulp from cornstalks.

These studies showed that various kinds of paper could be made from cornstalks. The fact that the cortex fibers were most valuable and the effects of pith on yields, quality and costs were brought out. It is almost impossible to bleach pith. The facts established in these studies are for the most part still true.

In 1928, looking to full-scale pulp mill operation, a pilot plant to produce paper pulp from cornstalks was erected at Danville, Illinois. This plant produced a considerable tonnage of pulp which was used in experimental paper runs by a number of paper mills. More than a hundred newspaper, magazine, and farm journal publishers printed editions on paper made to the extent of 60 percent cornstalk pulp mixed with wood pulp. This venture failed, partly due to depressed business conditions, but also to unsolved problems, particularly those of collection and storage of the stalks.

The successful use of cornstalks for the manufacture of paper depends on the solution of several difficult problems. First and foremost is the problem of economical collection and storage of stalks. Leaves have little value for making paper. For example, milo sorghum leaves were recently tested at the Laboratory for producing pulp; a yield of 23 percent of very low-grade pulp was secured. For this reason stalks collected for paper or board manufacture should be stripped of their leaves which, as noted above, have good feed and fertilizer value and should remain on the farm. Cornstalks contain about 25 percent pith, which is useful in making corrugating or other types of board, but is a distinct liability in making fine papers. The problem of making paper from cornstalks is similar to that of using bagasse, a subject recently discussed at some length by the writer. (24) Bagasse also contains a large percentage of pith. Wells and Steller (25) have also recently discussed practical means of separating and using cornstalk pith. Their solution would be to incorporate the separated pith with waste paper to make box board and cook the pith-free cortex fiber to produce pulps for fine papers. This scheme appears practical, provided the two types of paper mills were adjoining. The cortex fiber may be pulped by any of the following methods: soda, sulfate, sodium sulfite, Pomilio (caustic soda and chlorine), or nitric acid. Each of these processes will produce pulps of somewhat different characteristics, and yields will differ. The problem of chemical recovery and over-all costs will vary. Acid pulping processes, excepting nitric acid, are not suited to obtaining good pulps. The strengths of pulp will be found to decrease and yields increase in the following order in the processes: soda, sulfate, and neutral sodium sulfite.

It is the opinion of this Laboratory that agricultural residue pulps should be used in blends with wood fibers to produce specialty papers. Cornstalk pulp, free from pith, should be suitable for writing, book, magazine, litho, off-set, waxing, and a variety of high-grade papers.

At present, we are confining our attention at the Laboratory almost wholly to the use of wheat straw for producing paper pulps. The collection and storage problem for wheat straw has been pretty well solved. There is no pith problem with wheat straw. It is produced widely and to the extent of about 70 million tons per year. The 25 mills comprising the strawboard industry use 800,000 tons annually. We are now obtaining 50 percent yields of screened, bleached (70 brightness) fine paper pulp on the basis of dry straw by a neutral sodium sulfite cooking process. A mill in Holland has been using our process for more than a year to produce fine papers, and some mills in this country are expressing interest in producing this pulp.

From this discussion, I believe you will see that a growing industrial use for corncobs to supply a variety of practical needs has been developed and that industrial uses of cobs are expanding. Methods for collecting and handling cobs have been perfected so that they can be obtained economically.

On the other hand, for cornstalks no economical methods for collecting and storing exist. Consequently there is no industrial use for them, and what use previously existed has now been abandoned. Unless and until this primary problem is solved, there will continue to be no industrial use for stalks.

LITERATURE CITED

1. Morrison, E. B. Feeds and Feeding. The Morrison Publishing Co. Ithaca, New York (1939) pp. 305-306.

2. Brodell, A. P., and Walker, H. R. Harvesting of the Corn Crop. Bur. Agr. Econ., U. S. Dept. Agriculture Mimeograph Report F. M. 49. April 1945.

3. Van Lanen, J. M., Tanner, F. W. Jr., and Peiffer, Shirley E. Composition of Hybrid Corn Tassels. Cereal Chemistry 23: 428-432. July 1946.

4. University of Wisconsin Agricultural Experiment Station. What's New in Science. Bul. 466. Pt. II. 61st. Ann. Rpt. of the Director, for year ending June 30, 1944. May 1945 p. 54.

5. Burroughs, W., Gerlaugh, P., Schalk, A. F., Silver, E. A., and Kunkle, L. E. The Nutritive Value of Corn Cobs in Beef Cattle Rations. Jour. Animal Sci. 4 (7): 373-386. Nov. 1945.

6. Gerlaugh, P., Burroughs, W., and Kunkle, L. E. The Value of Corn Cobs in Rations for Fattening Steers. Mimeograph series No. 52, Ohio Agr. Expt. Sta.

7. Lathrop, E. C., and Shollenberger, J. H. Corncobs -- Their Composition, Availability, Farm and Industrial Uses. Northern Regional Research Laboratory, Bur. Agr. and Indust. Chem., U. S. Department of Agr., Mimeographed Cir. ACE-190. Revised Dec. 1948.

8. Winter, P., Dunning, J. W., and Dallas, D. The Storage of Corncobs and other Agricultural Residues for Industrial Use. Agr. Eng. 29: No. 1. 11-13 Jan. 1948.

9. Lathrop, E. C., and Aronovsky, S. I. Soft-Grit Blasting of Metals. Compressed Air Mag. 50: 268-272. 1945.

10. Clark, T. F., Williamson, R. V., and Lathrop, E. C. Agricultural Residues in Plastics. Part I. Agricultural Residue Flours. Modern Plastics 23: 158-160, 214, 216, 218. 1945.

11. Williamson, R. V., Clark, T. F., and Naffziger, T. R. Agricultural Residues in Plastics. Part II. Plasticizers and Inorganic Extenders in 25-percent Phenolics. Modern Plastics 23: 177-180, 220, 222. 1946.

12. Cass, O. W. Chemurgic Digest 6: 97-99. March 1947.

13. Anonymous. Production of Furfural. Chem. Met. Engr. 52 (7) : 132-35. 1946 .

14. Dunning, J. W., and Lathrop, E. C. The Saccharification of Agricultural Residues. A Continuous Process. Indus. and Engin. Chem. 37: 24. 1945.

15. Langlykke, A. F., Van Lanen, J. M., and Fraser, D. R. The Production of Butyl Alcohol from Xylose Saccharification Liquors. Indus. and Engin. Chem. (In press.)

16. Sweeney, O. R., and Emley, W. E. Manufacture of Insulating Building Board from Cornstalks. Natl. Bur. Standards Mis. Pub. M-112. 1930.

17. Lathrop, E. C., Naffziger, T. R., and Williamson, R. V. The Small Rural Industry. A Study of the Possibility of Making Insulating Board from Straw. Circ. No. 762, U. S. Dept. Agr. August 1947.

18. Lathrop, E. C., Naffziger, T. R., and Williamson, R. V. The Small Rural Industry--A Study of the Possibility of Manufacturing Insulating Board from Straw. II. Experimental Development--Plant Design and Operation. Processed Circular No. AIC-170, Bur. Agr. and Indust. Chem., U. S. Dept. Agr. 1948.

19. Brand, C. J. Crop Plants for Papermaking. Circular No. 82. Bur. Plant Ind., U. S. Dept. Agr. August 31, 1911.

20. Weber, H. A. Cellulose from Cornstalks. Indus. and Engin. Chem. 21: 270-275. 1929.

21. Weber, C. G., Shaw, M. B., and O'Leary, M. J. Papermaking Quality of Cornstalks. Misc. Pub. M-147 Nat'l. Bur. Standards. Feb. 1935.

22. Sweeney, O. R., and Arnold, L. K. Production of Paper from Cornstalks. Iowa Eng. Expt. Sta. Bul. 100, Iowa State College. Sept. 10, 1930.

23. Schafer, E. R. The Utilization of Fibrous Plants for Pulp and Paper. A Digest of the Results Available at the Forest Products Laboratory by Investigations of the U. S. Dept. Agr. Forest Products Laboratory, U. S. Dept. Agr. Oct. 1931.

24. Lathrop, E. C. The Industrial Utilization of Sugarcane Bagasse. Sugar Journal 10, (6): 5-7, 19-30. Nov. 1947.

25. Wells, S. D., and Steller, R. L. Utilization of Cornstalks in the Manufacture of Paper and Paper Board. Paper Trade Jour. 116 (15) 45-51. Apr. 15, 1943.